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# NAVORD REPORT

5702

MISCELLANEOUS WIND - TUNNEL TESTS ON THE LOW - DRAG BOMB (U)

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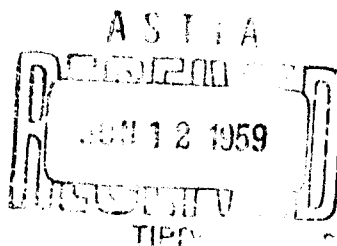


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## U. S. NAVAL ORDNANCE LABORATORY

### WHITE OAK, MARYLAND

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**Aerodynamic Research Report 14**

**MISCELLANEOUS WIND-TUNNEL TESTS ON THE LOW-DRAG BOMB**

Prepared by:

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**ABSTRACT:** <sup>✓</sup> Results are presented in this report of several wind-tunnel tests on the ~~Low-Drage~~ Bomb performed at the Naval Ordnance Laboratory, White Oak, Maryland and the National Bureau of Standards. The tests were:

- (1) <sup>✓</sup> a. Free-spin tests of a number of configurations performed at the National Bureau of Standards.
- (2) <sup>✓</sup> b. Free-spin tests of a number of configurations performed at the Naval Ordnance Laboratory, White Oak, Maryland.
- (3) <sup>✓</sup> c. Pitch-damping measurements of several configurations performed in the Naval Ordnance Laboratory Aeroballistics Tunnel No. 1.
- (4) <sup>✓</sup> d. Limited roll-damping tests of the basic Low-Drage Bomb shape obtained in the Naval Ordnance Laboratory Aeroballistics Tunnel No. 1.

Tests <sup>1</sup>~~a~~ and <sup>2</sup>~~b~~ were performed to obtain configurations which would free spin in a uniform manner for angles of attack from 0 to 90° degrees with no roll speed-up, roll slow-down or roll reversal. Tests ~~2~~ and ~~a~~ were performed to obtain data on the basic ~~Low-Drage~~ Bomb and several of the configurations which appeared good from the free-spin tests at the National Bureau of Standards.

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**22 September 1958**

Wind-tunnel tests on the Low-Drag Bomb were performed at the request of the Bureau of Ordnance (reference (a)). The wind tunnel tests were performed under task number 230-886/64057/02040. Previous reports on the Low-Drag Bomb are given in references (b) through (h).

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By direction

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MISCELLANEOUS WIND-TUNNEL TESTS ON THE LOW-DRAG BOMB

INTRODUCTION

1. The standard Navy Low-Drag Bomb is a clipped fin version of the bomb shape developed by Douglas Aircraft. The Low-Drag Bomb size varies from small practice bombs to 2000 pound bombs.

2. A small percentage of the bombs dropped go into circular yaw and give rather large dispersions. Some of the tests presented in this report were aimed at finding configurations which would not go into circular yaw. The remaining data were obtained to fill in the aerodynamic data needed for range tables for the Low-Drag Bombs.

Symbols

|                                  |   |
|----------------------------------|---|
| A                                | reference area ( $\pi d^2/4$ )  |
| $A_p$                            | wing-panel area (sq. ft.)   |
| b                                | total wing span (ft.)   |
| c.g.                             | center of gravity 3.64 calibers from the nose   |
| $C_L$                            | static rolling-moment coefficient ( $M_g/qAd$ )   |
| $C_{L\delta}$                    | roll-moment coefficient due to fin cant<br>( $C_{L(2^\circ \text{ fin cant})} - C_{L(0^\circ \text{ fin cant})}/\delta$ ) |
| $C_{Lp}$                         | roll-damping moment coefficient<br>( $4I_A/\rho V b^2 A_p n \ln(P/P_0)/\Delta t$ )  |
| $C_{M_q} + C_{M_{\dot{\alpha}}}$ | aerodynamic damping coefficient ( $-16/\pi K_H$ )   |
| d                                | reference diameter (caliber)(1.499 in.)   |
| $I_A$                            | axial moment of inertia (slugs-ft <sup>2</sup> )  |
| I                                | transverse moment of inertia about the c.g. (slugs-ft <sup>2</sup> )  |
| $K_H$                            | ballistic damping coefficient   |
| L                                | model length (ft.)(see Figure 30)   |
| $M_g$                            | rolling moment (in-lbs)   |
| n                                | number of fins  |
| p                                | roll rate (rad/sec)   |
| q                                | dynamic pressure (psi)  |
| Re                               | Reynolds number (see Figure 30)   |

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|                |   |
|----------------|---|
| t              | time (seconds)  |
| V              | free-stream velocity (ft/sec)                                     |
| $\alpha$       | angle of attack (deg)   |
| $\bar{\alpha}$ | average angular amplitude (deg)                                   |
| $\theta$       | fin bend angle (deg - see Figure 2)                               |
| $\delta$       | fin cant angle (rad or deg)                                       |
| $\epsilon$     | trailing edge bend (deg - see Figure 2)                           |
| $\gamma$       | fin orientation angle (deg)                                       |
| $\rho$         | air density (slugs/cu. ft)  |
| $\mu$          | dynamic damping coefficient $(-2I \ln(\alpha/\alpha_0)/\Delta t)$ |
| $\phi$         | angle of roll (deg)   |
| $\lambda$      | fin sweep angle (trailing edge)(deg)(+ denotes sweep back)        |

Free-Spin Tests

3. The free-spin test instrumentation for the tests performed at the National Bureau of Standards consisted of a model mounted on ball bearings, which allowed the model to free spin, and a Strobotac to measure the spin rate. The instrumentation from the NBS arrangement differed at NOL in that a tachometer was substituted for the Strobotac. The model is allowed to free spin while the angle of attack was varied. Model stall during the angle of attack variation has been termed "free stall". At the NBS it was possible to stop the model from spinning at any desired angle of attack by pulling a string tight against the model. The model would normally resume spinning when the string was released. The term "forced stall" has applied when the model remained stationary. In regions beyond the stall the model will tend to spin in either direction. Roll reversal data are not included in this report.

Roll-Damping Tests

4. The instrumentation for the roll-damping tests included an external drive air turbine powered model and a magnetic clutch to allow instantaneous release of the model from the driving turbine. The roll-damping coefficients were obtained by driving a model up to some spin rate and releasing the magnetic clutch which stopped the power to the model. The spin rate was recorded continuously as a function of time.

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**Pitch-Damping Models and Instrumentation**

5. The damping models were dynamically balanced about the scaled full-scale center of gravity. A shaft whose axis was normal to the longitudinal axis of the model was passed through the center of gravity and was attached to the model by means of precision ball bearings of very low frictional torque. The models were thus able to rotate in the pitch plane about a transverse axis which passes through the center of gravity. The models are allowed to oscillate and the motion is recorded with a 16 mm movie camera.

**Data Reduction for Dynamic Pitch Damping**

6. The technique is described in detail in reference (1). Briefly the data reduction consists of two phases: reading the film and fitting an envelope to the data obtained from the film. From the film the angle of the model is obtained for each frame of film using a comparator. The time record is obtained from the camera speed (64 frames per second). The angular deflection plotted against time yields a damped sine motion. The envelope of the motion is faired. In true harmonic damping, this envelope would be of the form  $\alpha = \alpha_0 e^{-\mu t/2I}$ . Damped harmonic motion requires that the restoring moment be linear; this is not always the case. However, by assuming the harmonic condition for small increments along the envelope, the damping coefficient ( $\mu$ ) can be obtained as a function of angular deflection by obtaining an average  $\mu$  for an average angle. The damping coefficient ( $\mu$ ) is related to  $K_H$  by the equation

$$K_H = \frac{\mu}{\rho V d^4}$$

**Models**

7. The models are divided into 4 sets; static, free-spin NOL, free-spin NBS, and damping. A sketch of the Low-Drag Bomb is shown in Figure 1. Sketches of the three fin shapes being investigated in detail are given in Figure 2. The fin shapes are for the basic bomb with 2 degree fin cant, the "dog ear" and the bent fin.

8. Photographs of these configurations (damping models) are presented in Figures 3, 4, and 5. A sketch of the box fin configuration is also given in Figure 2 while a photograph of the model is given in Figure 6. A photograph of a representative model with vanes is shown in Figure 7.



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9. An index of the photographs of some of the models tested at NBS are given in Table 1 (Fig. 8 through 21). Rectangular fins were made for many of the free-spin. ~~As the case of manufacturing.~~ A complete description of the fins is given in Table 2.

**Test Programs**

10. Free-spin tests at the Naval Ordnance Laboratory. Some preliminary tests have been completed at the Naval Ordnance Laboratory. Figure 22 shows the free-spin performance of the Low-Drag Bomb at various Mach numbers and to angles of attack of 24 degrees. At a Mach number of 0.90 the bomb was tested up to an angle of attack of 56 degrees. The bomb showed a slight tendency to speed up in the angle of attack range 0 to 15 degrees. It rotated at a constant spin rate for an angle of attack from 15 degrees to 31 degrees. The bomb stopped completely at an angle of attack of 32 degrees (increasing angle of attack). The bomb would not spin from 32 to 56 degrees. Figure 23 is a plot of the spin rate versus angle of attack for several configurations. In addition a configuration with vanes (Figure 7) was tested at Mach number 0.80. At angles of attack from 0 to 24 degrees the spin rate remains fairly constant for vane deflections of 0 and 5 degrees. The angle of attack range will have to be increased to 90 degrees before definite conclusions can be drawn about the roll performance.

11. Static roll tests (induced rolling moment). As an extension of the roll program, the roll due to fin cant was measured statically using alternately a zero and a two degree fin cant. The results are presented in Figure 24 in comparison with NOL firing range data.

12. Roll damping tests at the Naval Ordnance Laboratory. Rolling damping tests were made at a Mach number of 0.34 over an angle of attack range from 0 to 90 degrees and at a Mach number 0.80 over an angle of attack range from 0 to 20 degrees. The results are presented in Figure 25.

13. Pitch damping. The results of a test to determine pitch damping at a series of Mach numbers for the bomb with 2-degree fin cant, beveled fin, "dog ear" fin and a box fin are presented in Figures 26 through 29.

14. Free spin test at National Bureau of Standards. A total of 46 configurations were tested at the NBS. The configurations consisted of varying the span, number of fins, bending the tips, "dog earing" the tips, tangent fins, wrap around fins and twisting the fins. A summary of the NBS data and an index to the photographs are given in Table 1.

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15. The purpose of the test was to determine a fin shape that would not "free" or "force" stall. At the same time the bomb model should not rotate at spin rates much beyond 500 cycles per second. This limited the fin cant of the basic bomb to about 2 degrees.

16. The tests were performed at a wind speed of 160 ft/sec.

**Results**

17. The configuration considered best from the free-spin performance were the 67.5 degree bent tip and the 15 degree "dog ear". It is believed that a tangent fin configuration could be found that would not stall. Configuration 5(NBS) had a roll reversal region at  $\alpha = 6$  degrees. A slight change in the fin angle would probably yield a fin configuration which would not stall.

18. The box shroud configuration has been included in the low-drag program since this is a configuration which has a small side moment and a small induced rolling moment. Both are objectionable and contribute to the catastrophic yaw problem (reference (j)). The box shroud has poor stability at supersonic Mach numbers (reference (h)).

19. The NOL free-spin results are inconclusive. The results are presented only as a progress report. Figure 22 shows that there is a rather large effect of Mach number or Reynolds number (or both) on the free-spin performance. The tests of the various configurations will continue and some of the configurations will be tested up to angles of attack of 90 degrees if possible.

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TABLE I  
INDEX TO THE NATIONAL BUREAU OF STANDARDS FREE SPIN TESTS

| MODEL NO. | Identification of Models<br>(All angles in degrees) | Roll Performance (All<br>angles in degrees)  | RPM at<br>$\alpha = 0^\circ$ | Fig. No. of<br>Photograph |
|-----------|---|--|------------------------------|---------------------------|
| 1         | Bent Fin, $\beta = 45$ for 2<br>Fins                | Stalled between $\alpha = -18$<br>and $-32$<br>Reversed spin $\alpha = 43$ ,<br>Stalls between $\alpha = -43$<br>and $-47$ spin reversal $\alpha =$<br>$-47$ | 372                          |                           |
| 2         | Bent Fin, $\beta = 67.5$                            | Free Stall at $\alpha = -43$<br>Force Stall $\alpha = -19$   | 305                          | 8                         |
| 3         | Bent Fin, $\beta = 22.5$                            | No Free Stall<br>Force Stall $\alpha = -17$  | 270                          | 2, 5, 9                   |
| 4         | Small Tangent Fin, $\lambda = 0$                    | Free Stall at $\alpha = -9$<br>to $-26$  |                              | 10                        |
| 5         | Large Tangent Fin $\lambda = 0$                     | Spin Counterclockwise to<br>$\alpha = -6$<br>Free Stall $\alpha = -6$ to $-11$<br>Reverse Spin at $\alpha = -11$   | 760 at<br>$\alpha = -15$     | 11                        |
| 6         | Large Tangent Fin $\lambda = -15$                   | Free Stall $\alpha = -3$ to $-34$  |                              |                           |
| 7         | Large Tangent Fin $\lambda = 30$                    | Free Stall $\alpha = 0$ to $-8$<br>clockwise<br>Free Stall $\alpha = -29$ to $-35$<br>Free Stall $\alpha = -41$ to $-46$<br>counterclockwise                 |                              | 12                        |
| 8         | Extra Large Tangent Fin<br>$\lambda = 30$           | Free Stall $\alpha = 0$ to $-7$ ,<br>counterclockwise<br>Free Stall $\alpha = -7$ to $-57$ ,<br>clockwise  |                              | 13                        |

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TABLE I (Cont.)

|    |  |   |    |
|----|--|---|----|
| 9  | Large Radially Mounted,<br>$\lambda = 0$               | Free Stall $\alpha = -28$ to $-41$                                  | 14 |
| 10 | Large Radially Mounted,<br>$\lambda = 30$              | Free Stall $\alpha = -29$ to $-38$                                  |    |
| 11 | Extra Large Radially Mounted<br>$\lambda = -15$        | Free Stall $\alpha = -32$ to $-46$                                  |    |
| 12 | Extra Large Radially Mounted<br>$\lambda = 30$         | Free Stall $\alpha = -28$ to $-57$                                  |    |
| 13 | Extra Large Radially Mounted<br>$\lambda = 30, 3$ Fins | Free Stall $\alpha = -40$ to $-63$                                  | 15 |
| 14 | Wrap around 4 Fins in Line                             | Free Stall $\alpha = 0$ to $-24$                                    |    |
| 15 | Wrap around 3 Fins in Line                             | Free Stall $\alpha = 0$ to $-27$                                    |    |
| 16 | Wrap around 6 Fins in Line                             | Free Stall $\alpha = 0$ to $-16$                                    | 16 |
| 17 | Wrap around 6 Fins<br>Interdigitated                   | Free Stall $\alpha = 0$ to $-21$                                    | 17 |
| 18 | 4° Cant at Top   | Reverse Direction $\alpha = -41$                                    |    |
| 19 | 4° Cant at Bottom                                      | Free Spin Stall $\alpha = -50$<br>Reverses Direction $\alpha = -40$ |    |
| 20 | Small Span 3 Fins                                      | Poor Performance *  |    |
| 21 | Small Span 6 Fins                                      | Poor Performance  |    |
| 22 | Small Span 12 Fins                                     | Poor Performance  |    |
| 23 | Large Span 3 Fins                                      | Poor Performance  |    |

Poor Performance\* - Roll characteristics such that it was not advisable to spend time recording data.

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TABLE I (Cont)

|    |  |  |      |
|----|--|--|------|
| 24 | Large Span 6 Fins  | Force Stall $\alpha = -20$ to $-31$<br>Reverse Spin $\alpha = -42$                     | 18   |
| 25 | Large Span 12 Fins   | Poor Performance   |      |
| 26 | Same as No. 5 only<br>Reversed<br>Direction of Fin                               | Free Stall $\alpha = 0$ to $-8$ ,<br>clockwise<br>Forced Stall $\alpha = -13$ to $-20$ | 19   |
| 27 | $\lambda = 3$ , Tangent Fin  | No Free Stall<br>Forced Stall $\alpha = -45$ to $-90$                                  | 850  |
| 28 | $\delta = 30$ , Dog-ear Bent at<br>$\zeta = 30$ , Large Span                     | No Free or Forced Stall  | 2120 |
| 29 | $\delta = 30$ , Dog-ear Bent at<br>$\zeta = 30$ , 2 Fins Straight,<br>Large Span | Spin Rate Too High<br>No Date Taken  | 1750 |
| 30 | $\delta = 30$ , Dog-ear, Bent at<br>$\zeta = 30$ , Large Span*                   | No Free Stall<br>Forced Stall $\alpha = -19^\circ$<br>to $-32^\circ$                   | 945  |
| 31 | Wrap around, 4 Fins*<br>in Line  | Free Spin Stall $\alpha = -15$<br>to $-28$   |      |
| 32 | $\delta = 15$ , Dog-ear Bent at<br>$\zeta = 30$ , Small Span                     | Forced Stall Only $\alpha = -25$<br>to $-31$   | 790  |
| 33 | $\delta = 20$ , Dog-ear Bent at<br>$\zeta = 30$ , Small Span                     | Free Spin Stall $\alpha = -39$<br>to $-45^\circ$                                       | 550  |
| 34 | $\delta = 30$ , Dog-ear Bent at<br>$\zeta = 30$ , Small Span                     | Force Stall $\alpha = -47$ to $55$<br>No Free Stall                                    | 1830 |
| 35 | $\delta = 30$ , Dog-ear Bent at<br>$\zeta = 25$ , Small Span                     | Spin Rate Too Large  | 1250 |

TABLE I (Cont)

| 36 | B = 30, Dog-ear Bent at<br>C = 20, Small Span                    | Spin Rate Too Large   |                |
|----|--|---|----------------|
|    |  | 1200  |                |
| 37 | B = 30, Dog-ear Bent at<br>C = 15, Small Span                    | No Free Stall<br>Forced Stall $\alpha = -44$ to $-50$   | 750            |
| 38 | B = 30, Dog-ear Bent at<br>C = 15, Large Span*                   | No Free Stall<br>Forced Stall $\alpha = -44$ to $-47$   | 540<br>2<br>14 |
| 39 | B = 30, Dog-ear Bent at<br>C = 20, Large Span*                   | No Free Stall<br>Forced Stall $\alpha = -46$ to $-47$   | 885            |
| 40 | B = 35, Dog-ear Bent at<br>C = 10, Large Span*                   | No Free Stall $\alpha = -44$ to $-34$<br>Forced Stall $\alpha = -27$ to $-46$                                     | 640            |
| 41 | B = 30, Dog-ear Bent at<br>C = 17.5, Large Span*                 | No Free Stall $\alpha = -45$ to $-34$<br>Forced Stall $\alpha = -31$ to $-46$                                     | 770            |
| 42 | B = 30, Dog-ear Bent at<br>C = 10, Large Span*                   | No Free Stall<br>Forced Stall $\alpha = -43$ to $-47$<br>$\alpha = -22$ to $-23$<br>$\alpha = -31$ to $-33$       |                |
| 43 | Large Tangent Fin<br>$\lambda = 0$ , 1 Angle of<br>Attack on Fin | No Free Stall<br>Forced Stall $\alpha = -17$ to $-33$<br>$\alpha = -37$ to $-55$                                  | 440            |
| 44 | Large Tangent Fin<br>$\lambda = 0$ , 2 Angle of<br>Attack on Fin | No Free Stall<br>Forced Stall $\alpha = -21$ to $-34$<br>$\alpha = -44$ to $-49$                                  | 575            |
| 45 | Large Tangent Fin<br>$\lambda = 0$ , 3 Angle of<br>Attack on Fin | No Free Stall<br>Forced Stall $\alpha = -21$ to $-49$   | 495            |
| 46 | Basic Bomb Shape   | Free Stall $\alpha = 25$ to $35^\circ$<br>Forced Stall $\alpha = 20$ to $25^\circ$<br>$\alpha = 40$ to $50^\circ$ | 430<br>1, 2, 3 |

\* No Fin Cant, all not marked  $\alpha$  at a Fin Cant of 2 degrees.

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Table 2

BUREAU OF STANDARDS FREE SPIN TEST

FIN INFORMATION

| Model No. | SPAN (dia.) | BASE CHORD (dia.) | No. Fins | $\lambda$ in degrees | $\beta$ in degrees | $\epsilon$ in degrees | PLANFORM * |
|-----------|-------------|-------------------|----------|----------------------|--------------------|-----------------------|------------|
| 1         | 1.667       | 1.055             | 4        | 0                    | 45                 | 0                     | A          |
| 2         | 1.667       | 1.055             | 4        | 0                    | 45                 | 0                     | A          |
| 3         | 1.667       | 1.055             | 4        | 0                    | 45                 | 0                     | A          |
| 4         | 2.15        | 0.81              | 4        | 0                    | 0                  | 0                     | B          |
| 5         | 2.4         | 0.965             | 4        | 0                    | 0                  | 0                     | B          |
| 6         | 2.4         | 0.965             | 4        | -15                  | 0                  | 0                     | C          |
| 7         | 2.4         | 0.965             | 4        | 30                   | 0                  | 0                     | C          |
| 8         | 3.3         | 0.588             | 4        | 30                   | 0                  | 0                     | C          |
| 9         | 1.667       | 0.87              | 4        | 0                    | 0                  | 0                     | B          |
| 10        | 1.667       | 0.87              | 4        | 30                   | 0                  | 0                     | C          |
| 11        | 2.4         | 0.588             | 4        | -15                  | 0                  | 0                     | C          |
| 12        | 2.4         | 0.585             | 4        | 30                   | 0                  | 0                     | C          |
| 13        | 2.4         | 0.585             | 3        | 30                   | 0                  | 0                     | B          |
| 14        | 1.667       | 0.865             | 4        | 0                    | 0                  | 0                     | B          |
| 15        | 1.667       | 0.865             | 3        | 0                    | 0                  | 0                     | B          |
| 16        | 1.667       | 0.865             | 6        | 0                    | 0                  | 0                     | B          |
| 17        | 1.667       | 0.530             | 6        | 0                    | 0                  | 0                     | B          |
| 18        | 1.414       | 0.780             | 4        | 0                    | 0                  | 0                     | B          |
| 19        | 1.414       | 0.780             | 4        | 0                    | 0                  | 0                     | B          |
| 20        | 1.414       | 0.965             | 3        | 0                    | 0                  | 0                     | A          |
| 21        | 1.414       | 0.965             | 6        | 0                    | 0                  | 0                     | A          |
| 22        | 1.414       | 0.965             | 12       | 0                    | 0                  | 0                     | A          |
| 23        | 1.667       | 1.055             | 3        | 0                    | 0                  | 0                     | A          |
| 24        | 1.667       | 1.055             | 6        | 0                    | 0                  | 0                     | A          |
| 25        | 1.667       | 1.055             | 12       | 0                    | 0                  | 0                     | A          |
| 26        | 2.4         | 0.965             | 4        | 0                    | 0                  | 0                     | B          |
| 27        | 2.4         | 0.965             | 4        | 3                    | 0                  | 0                     | C          |
| 28        | 1.667       | 1.055             | 4        | 0                    | 30                 | 30                    | A          |
|           |             |                   | 4        | 2                    | 0                  | 0                     | A          |
| 29        | 1.667       | 1.055             | 4        | 2                    | 0                  | 0                     | A          |
| 30        | 1.667       | 1.055             | 4        | 0                    | 30                 | 30                    | A          |
| 31        | 1.667       | 0.865             | 4        | 0                    | 0                  | 0                     | B          |
| 32        | 1.414       | 0.965             | 4        | 0                    | 15                 | 30                    | A          |
| 33        | 1.414       | 0.965             | 4        | 0                    | 20                 | 30                    | A          |
| 34        | 1.414       | 0.965             | 4        | 0                    | 30                 | 30                    | A          |
| 35        | 1.414       | 0.965             | 4        | 0                    | 30                 | 25                    | A          |
| 36        | 1.414       | 0.965             | 4        | 0                    | 30                 | 20                    | A          |
| 37        | 1.414       | 0.965             | 4        | 0                    | 30                 | 15                    | A          |
| 38        | 1.667       | 1.055             | 4        | 0                    | 30                 | 15                    | A          |
| 39        | 1.667       | 1.055             | 4        | 0                    | 30                 | 20                    | A          |

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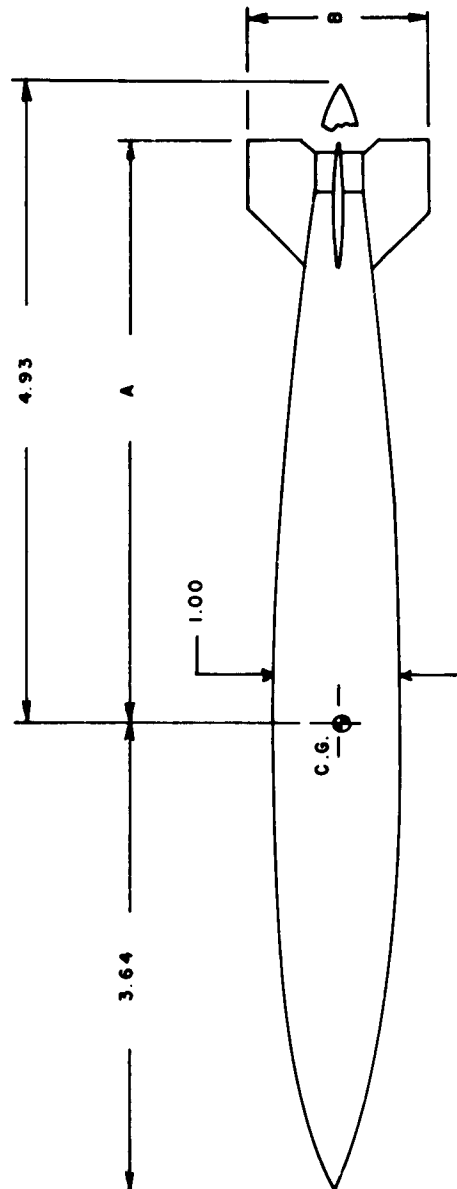
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Table 2 (Cont.)

| Model No. | Span (dia.) | BASE CHORD (dia.) | No Fins | $\lambda$ in degrees | $\beta$ in degrees | $\epsilon$ in degrees | PLANFORM * |
|-----------|-------------|-------------------|---------|----------------------|--------------------|-----------------------|------------|
| 40        | 1.667       | 1.055             | 4       | 0                    | 35                 | 10                    | A          |
| 41        | 1.667       | 1.055             | 4       | 0                    | 30                 | 17.5                  | A          |
| 42        | 1.667       | 1.055             | 4       | 0                    | 30                 | 10                    | A          |
| 43        | 2.4         | 0.965             | 4       | 0                    | 0                  | 0                     | B          |
| 44        | 2.4         | 0.965             | 4       | 0                    | 0                  | 0                     | B          |
| 45        | 2.4         | 0.965             | 4       | 0                    | 0                  | 0                     | B          |
| 46        | 1.4         | 0.965             | 4       | 0                    | 0                  | 0                     | A          |

- \* A - low drag planform (see Fig. 2)  
 B - rectangular planform  
 C - parallelogram planform

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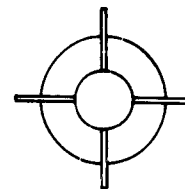
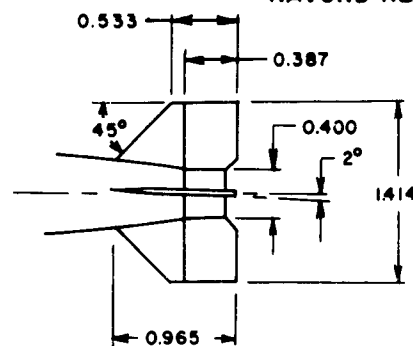


| FIN CONFIG. | A    | B     |
|-------------|------|-------|
| BASIC       | 4.52 | 1.414 |
| BOX         | 4.52 | 1.414 |
| DOG EAR     | 4.48 | 1.670 |
| BENT FIN    | 4.48 | 1.670 |

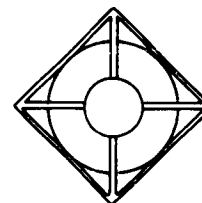
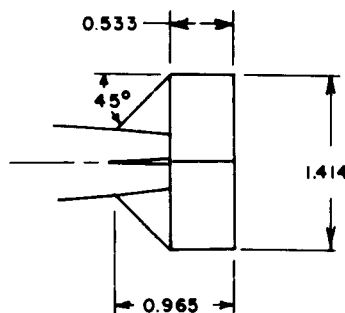
ALL DIMENSIONS ARE IN CALIBERS

FIG. 1 LOW DRAG BOMB

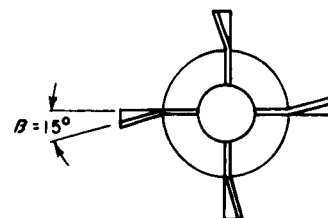
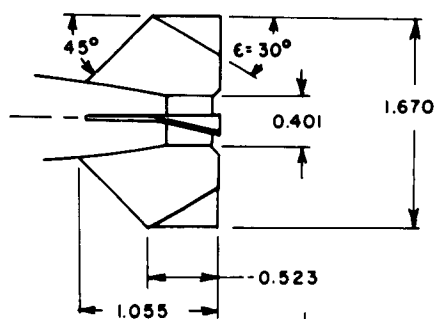
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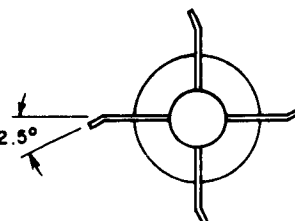
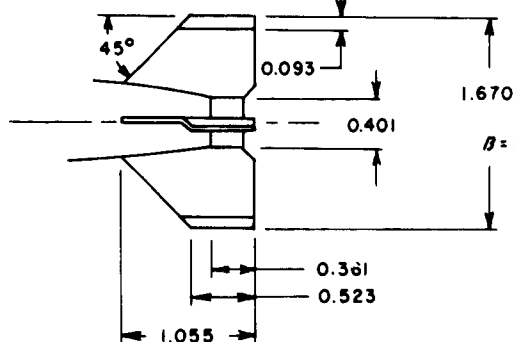
BASIC FIN



BOX SHROUD



DOG EAR



BENT FIN

ALL DIMENSIONS ARE IN CALIBERS

FIG. 2 FIN DIMENSIONS AND NOMENCLATURE  
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FIG. 3 BASIC CONFIGURATION

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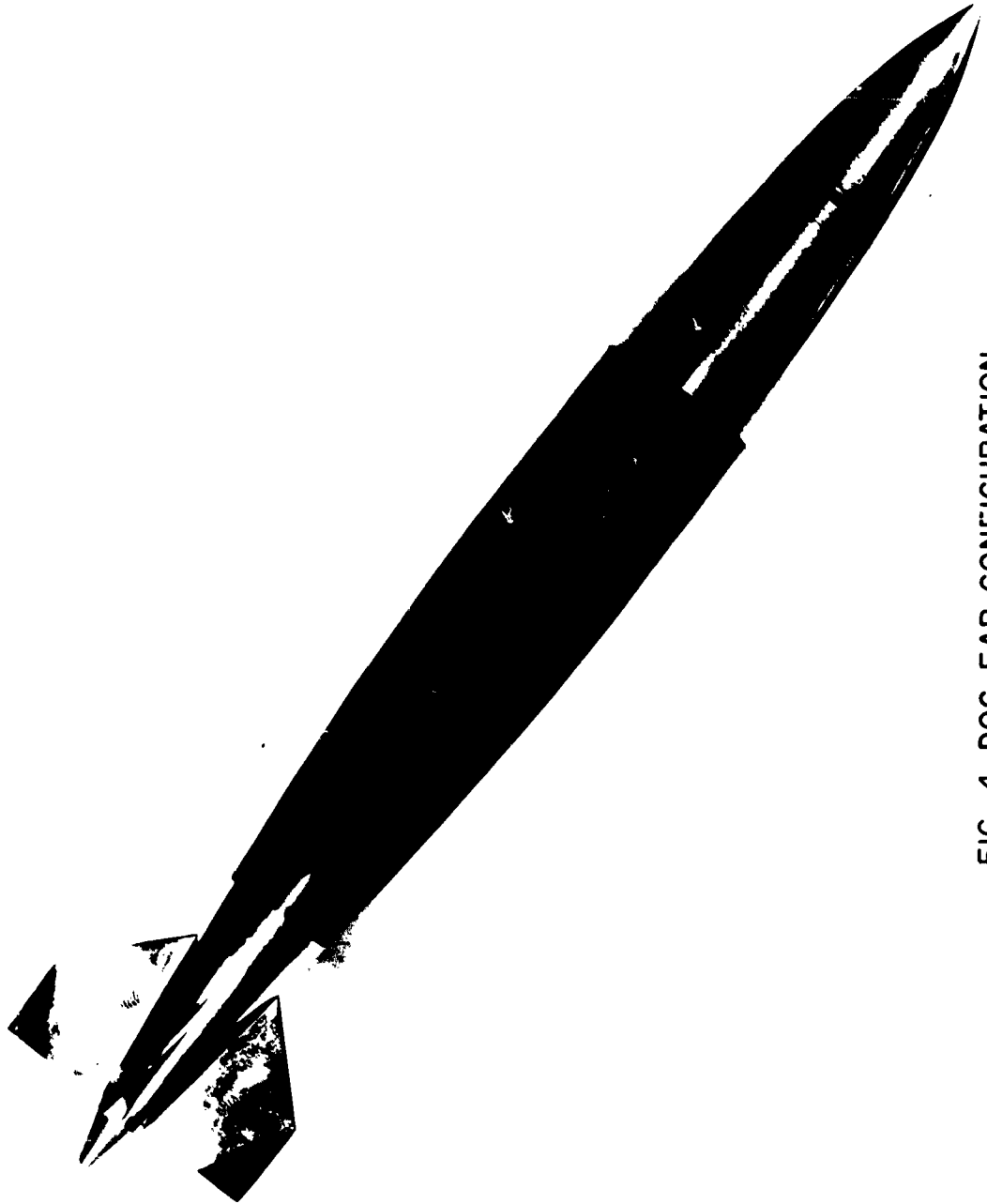


FIG. 4 DOG EAR CONFIGURATION

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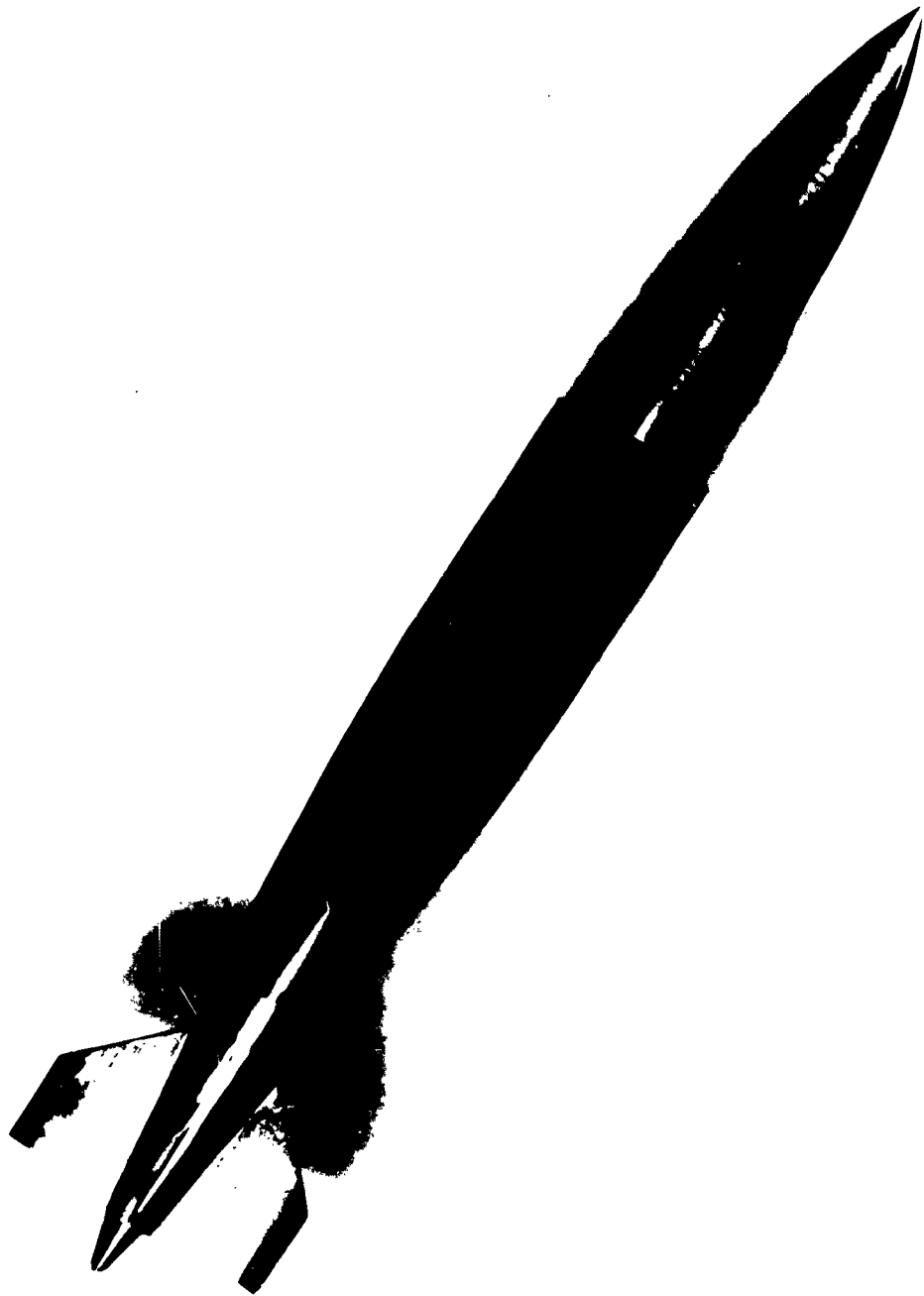


FIG. 5 BASIC BENT FIN CONFIGURATION  $\beta = 22.5^\circ$

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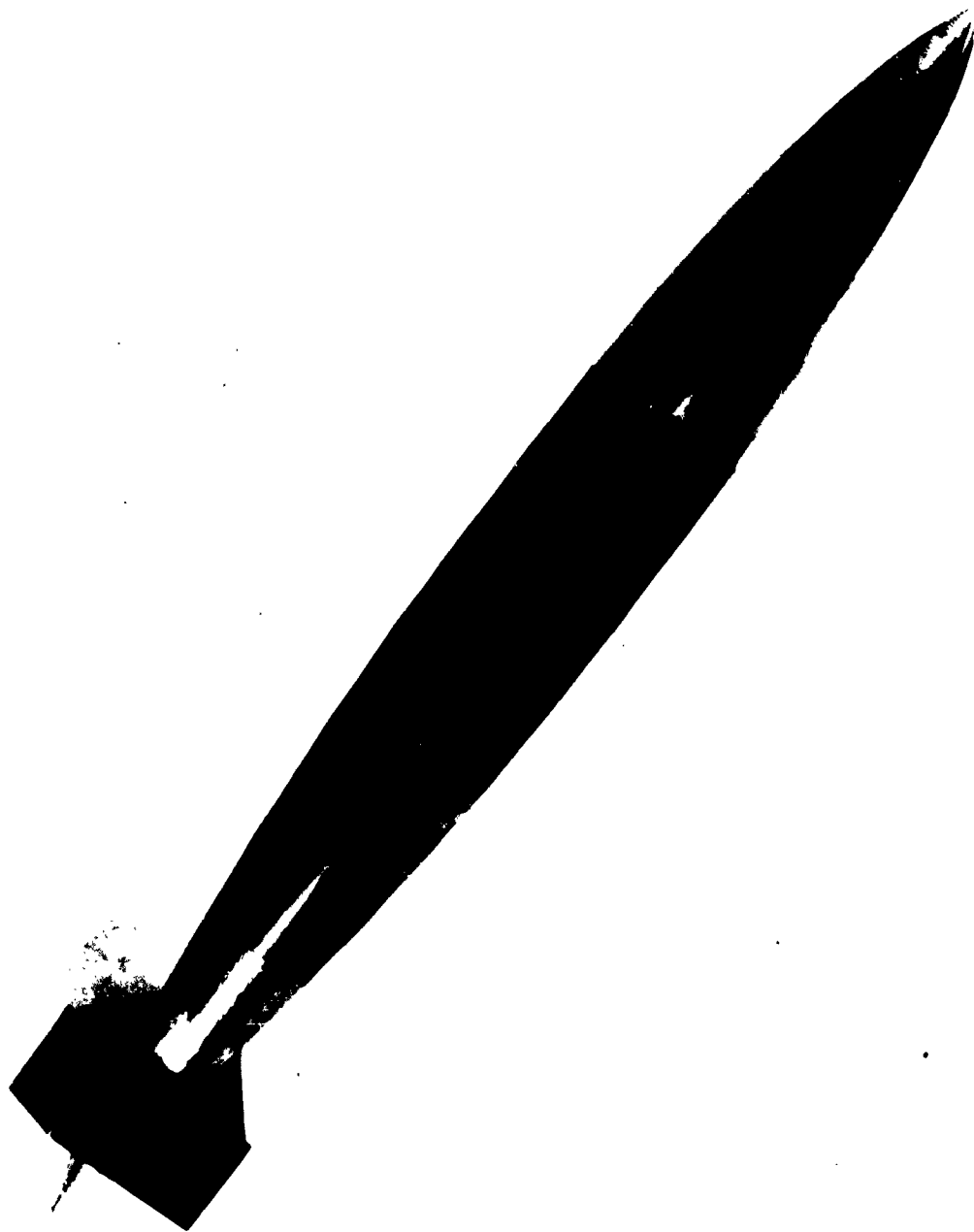


FIG. 6 BOX FIN CONFIGURATION

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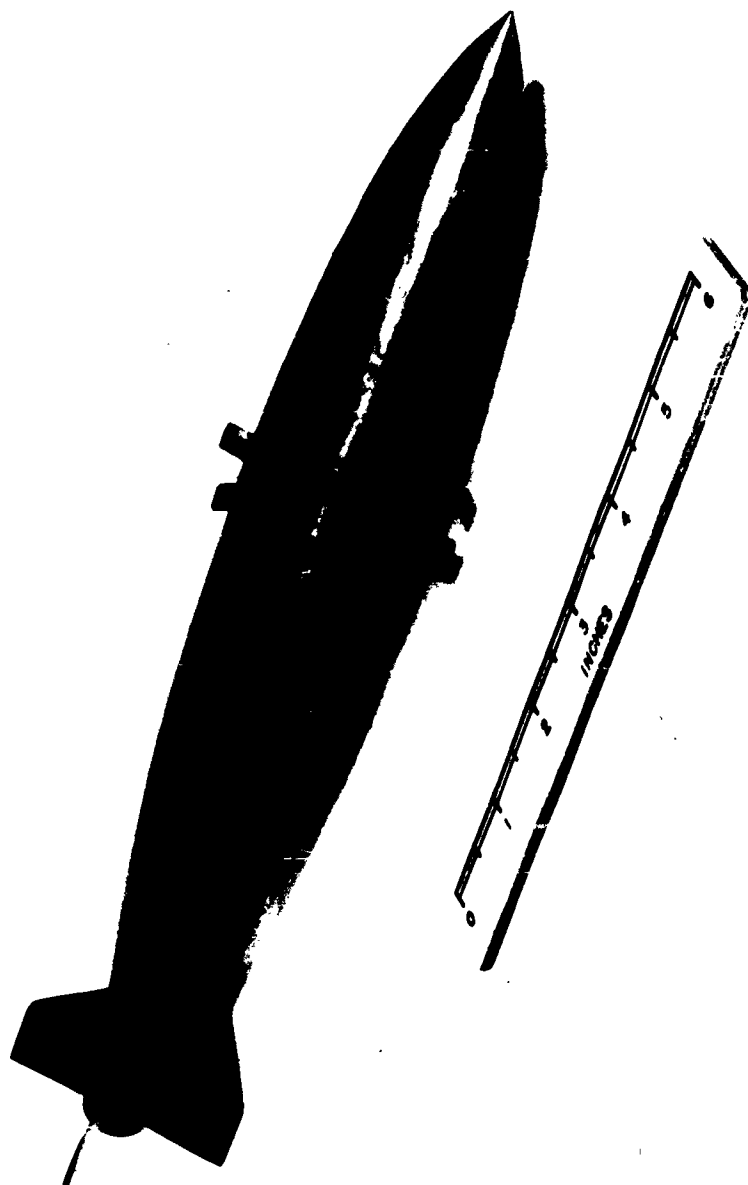


FIG. 7 VANE CONFIGURATION

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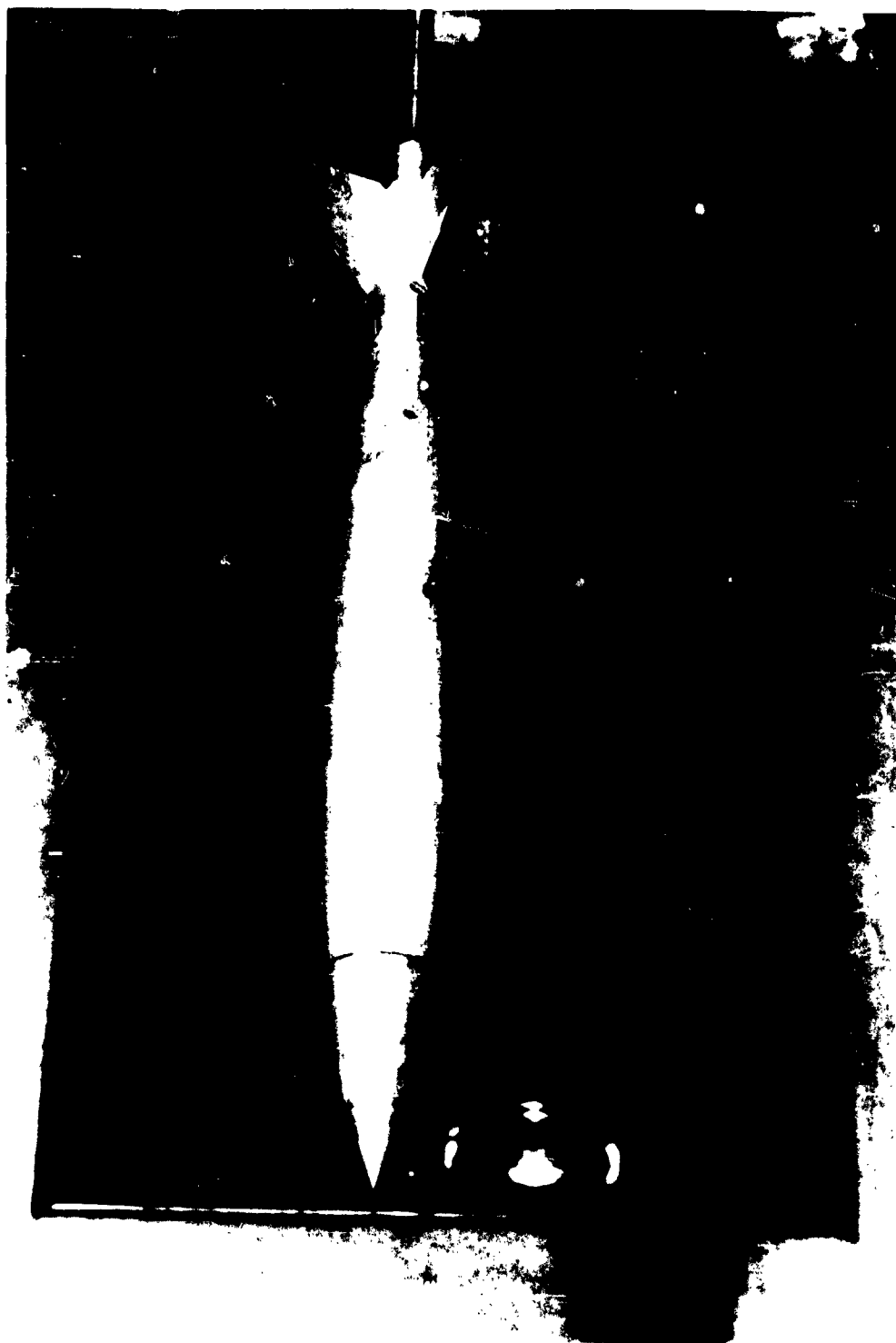


FIG 8 BENT FIN  $\beta = 67.5^\circ$

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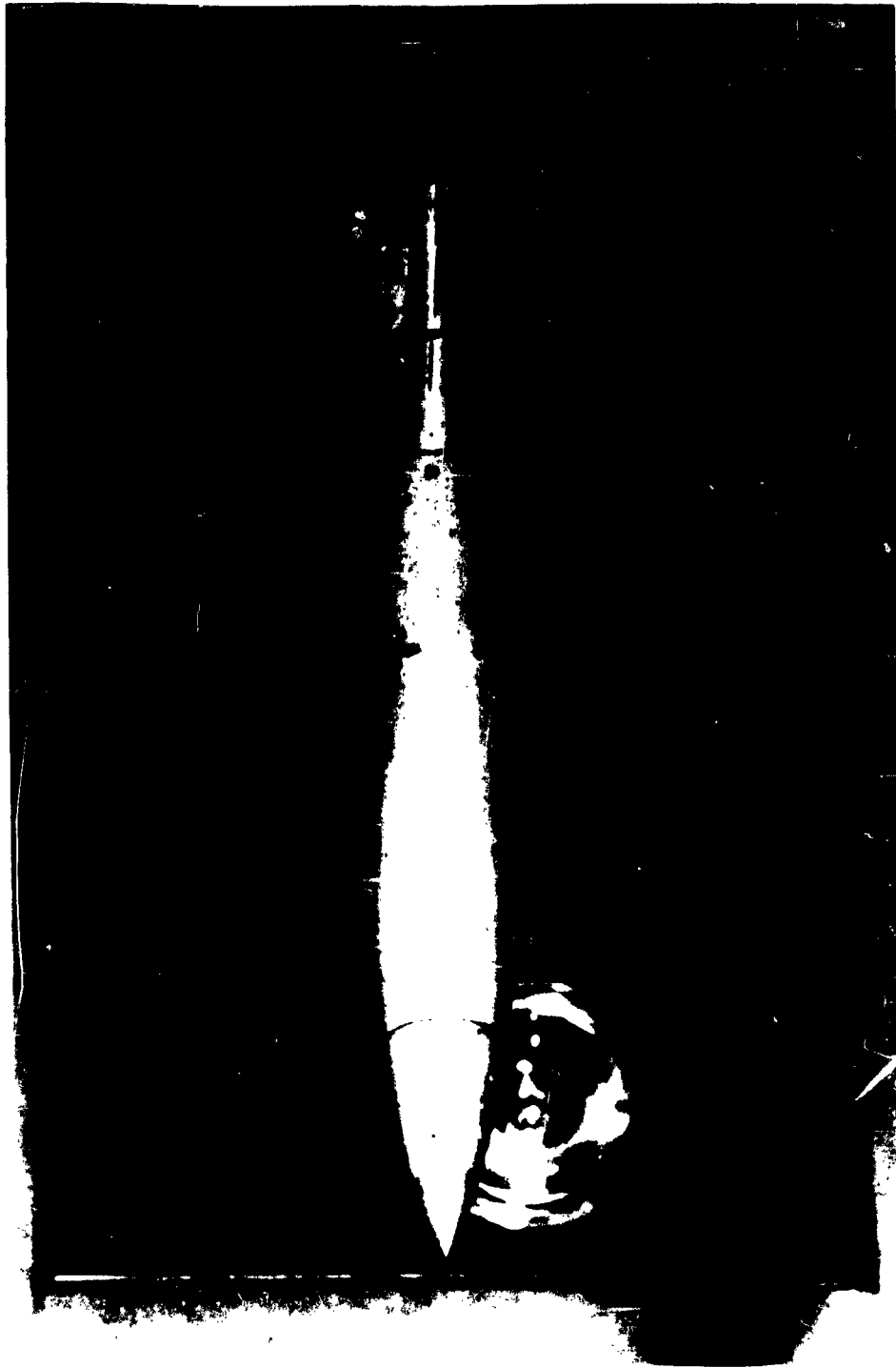


FIG. 9 BENT FIN  $\beta = 22.5^\circ$

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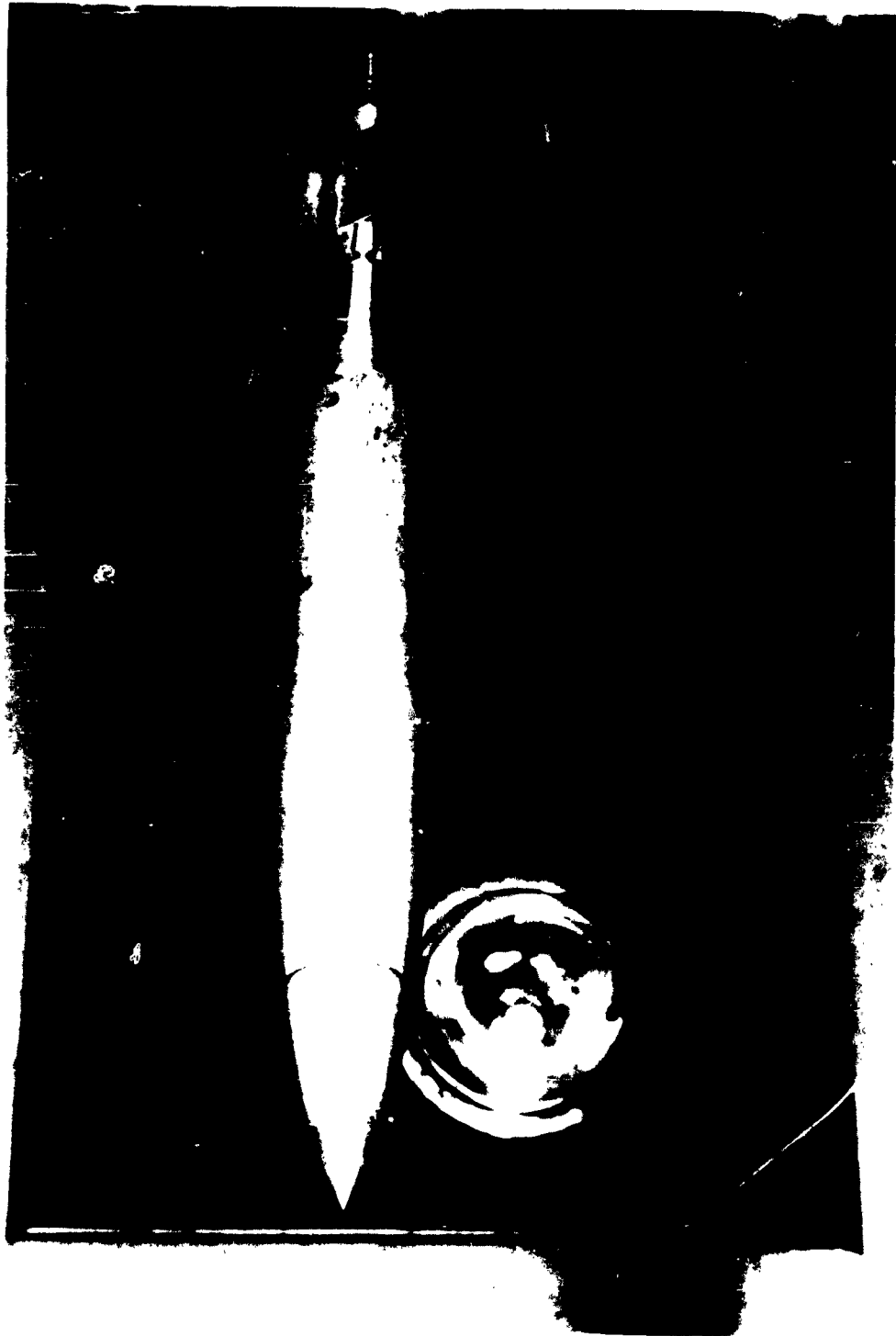


FIG. 10 SMALL TARGET FIN  $\lambda=0^\circ$

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FIG. 11 LARGE TARGET FIN  $\lambda=0^\circ$

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FIG. 12 LARGE TARGET FIN  $\lambda = 30^\circ$

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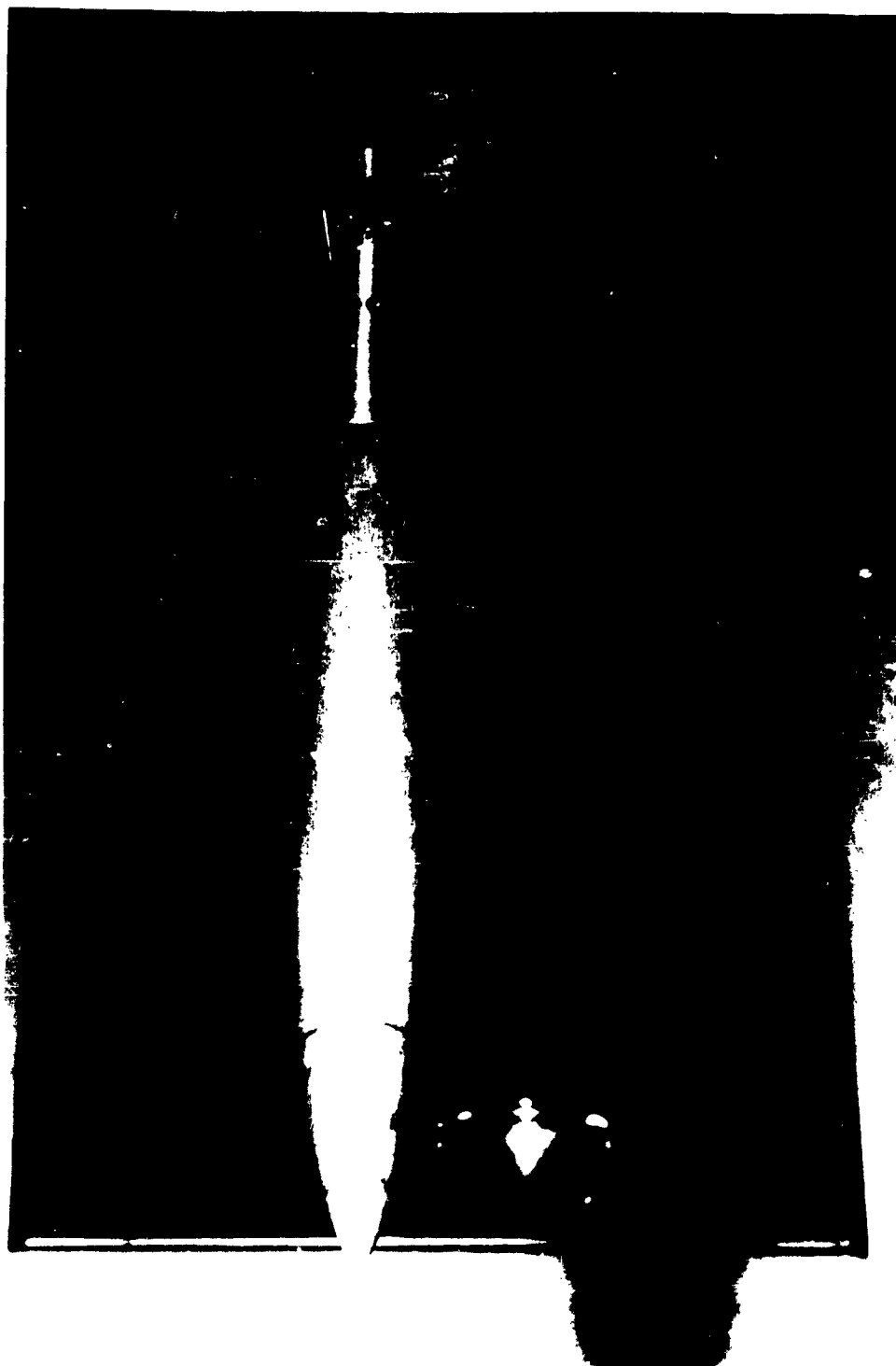


FIG. 13 EXTRA LARGE TARGET FIN  $\lambda = 30^\circ$

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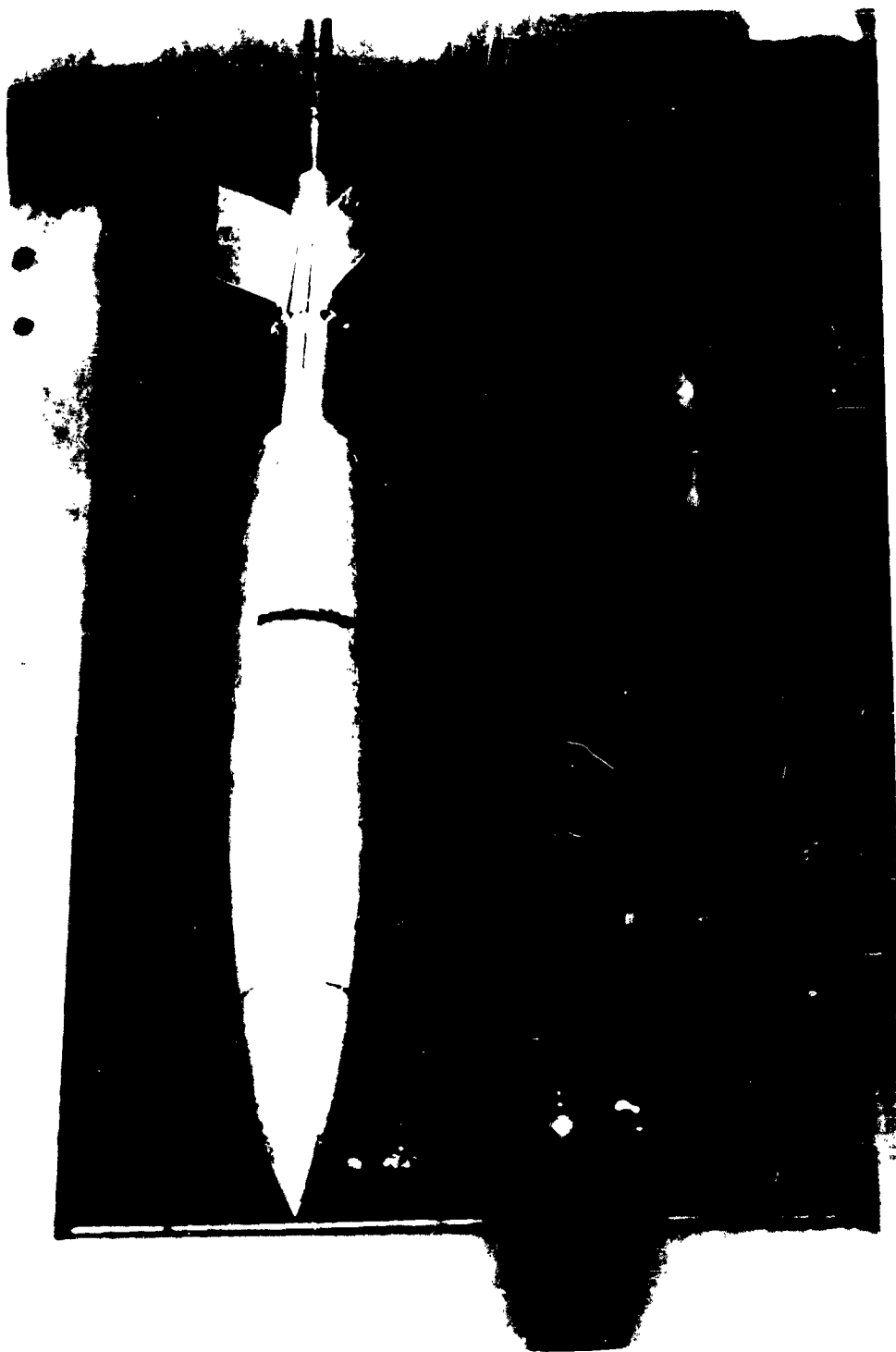


FIG. 14 LARGE RADIALLY MOUNTED  $\lambda=0^\circ$

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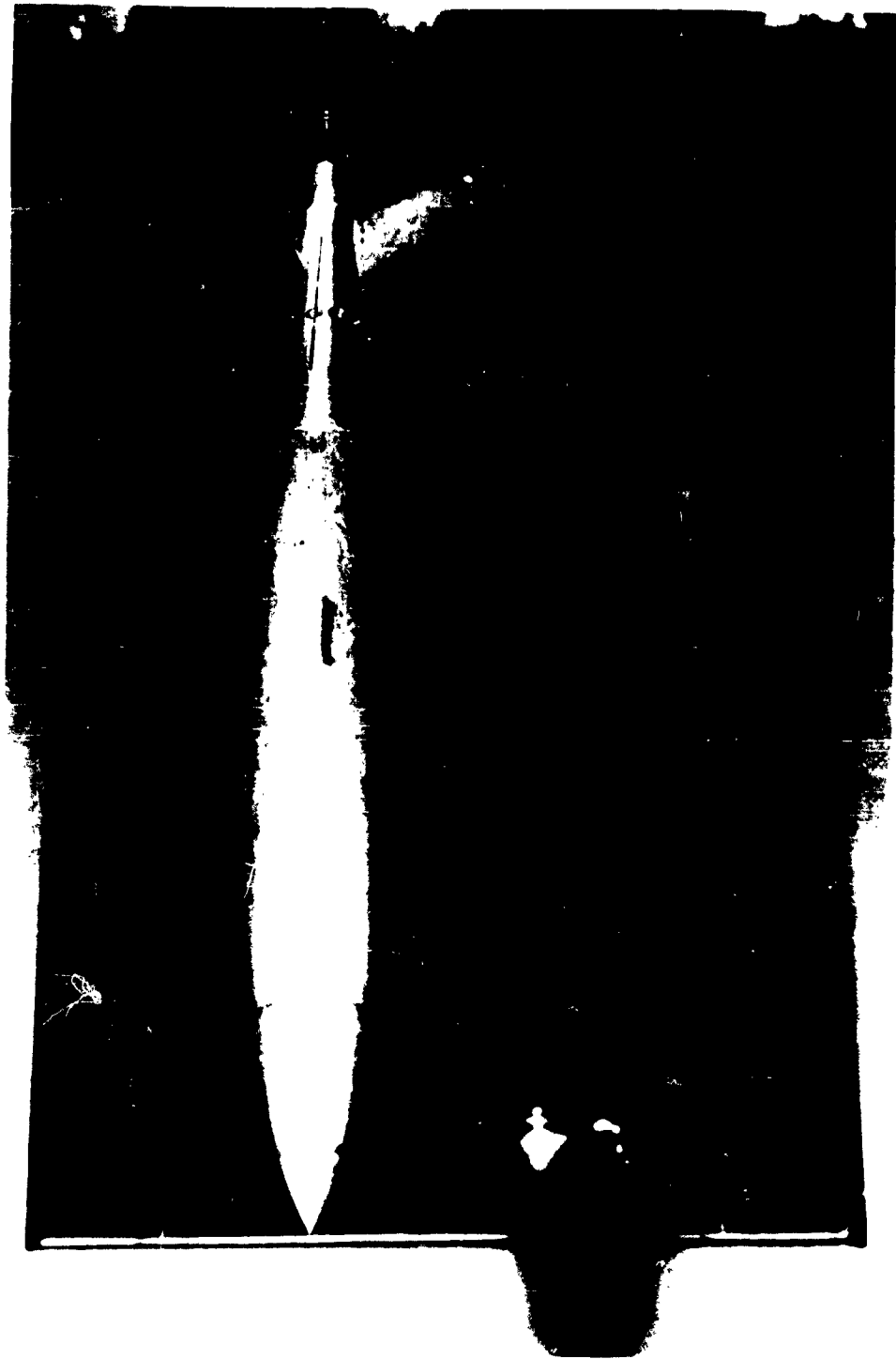


FIG. 15 EXTRA LARGE RADIALY MOUNTED  $\lambda=30^\circ$  3 FIN

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FIG. 16 WRAP AROUND 6 FINS IN LINE

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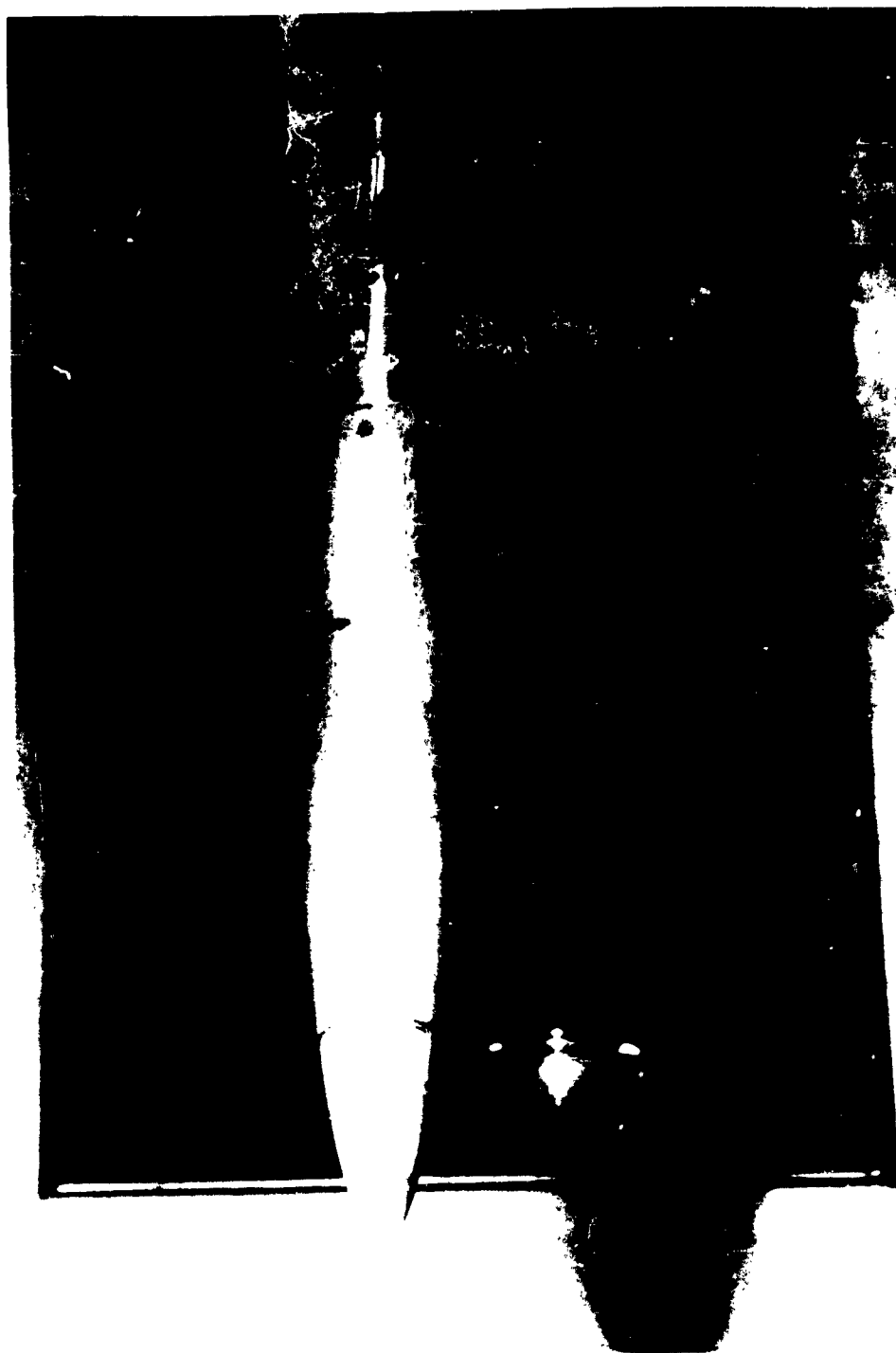


FIG. 17 WRAP AROUND 6 FINS INTERDIGITATED

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FIG. 18 LARGE SPAN 6 FINS

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FIG. 19 LARGE TANGENT FIN  $\lambda=0^\circ$  (BEND ANGLE REVERSE OF FIG. 11)

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FIG. 20 DOG EAR BENT AT  $\epsilon = 30^\circ$   $\beta = 30^\circ$  LARGE SPAN

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FIG. 21 DOG EAR BENT AT  $\epsilon = 30^\circ$ ; 2 FINS STRAIGHT, LARGE SPAN  $\beta = 30^\circ$

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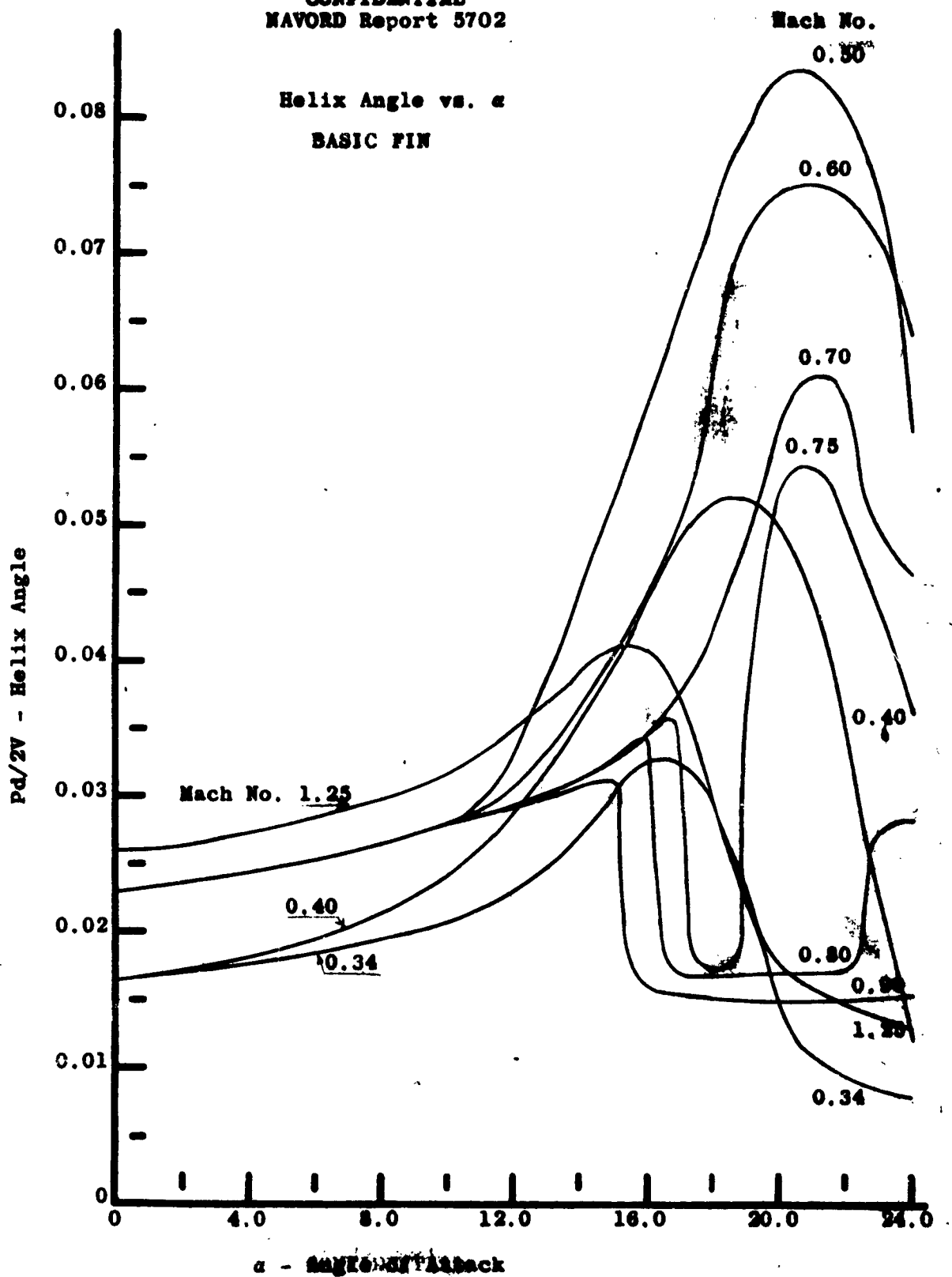


Figure 32

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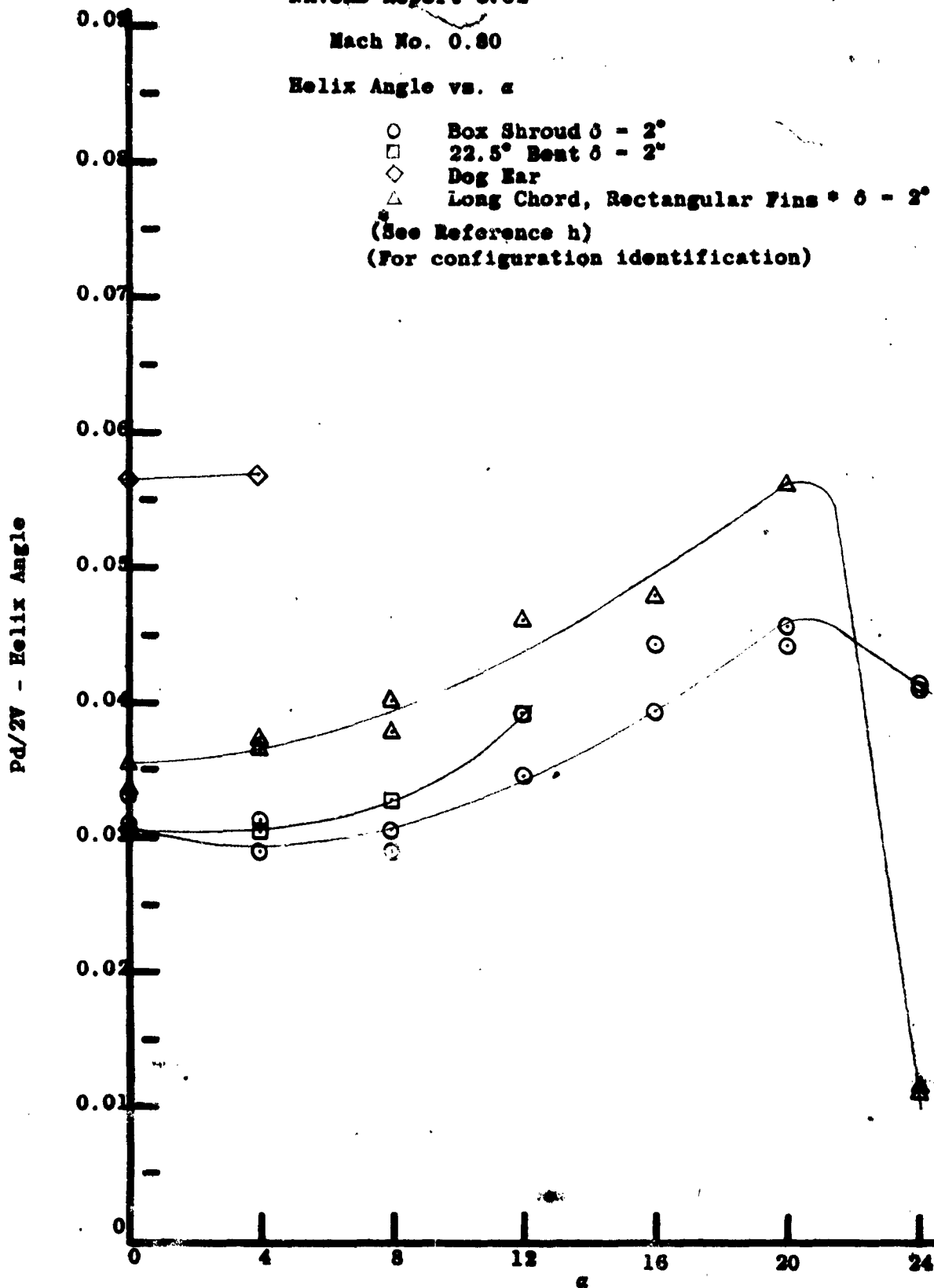
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Mach No. 0.80

Helix Angle vs.  $\alpha$

- Box Shroud  $\delta = 2^\circ$
- 22.5° Bent  $\delta = 2^\circ$
- ◇ Dog Ear
- △ Long Chord, Rectangular Fins \*  $\delta = 2^\circ$

(See Reference h)  
(For configuration identification)



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Figure 28



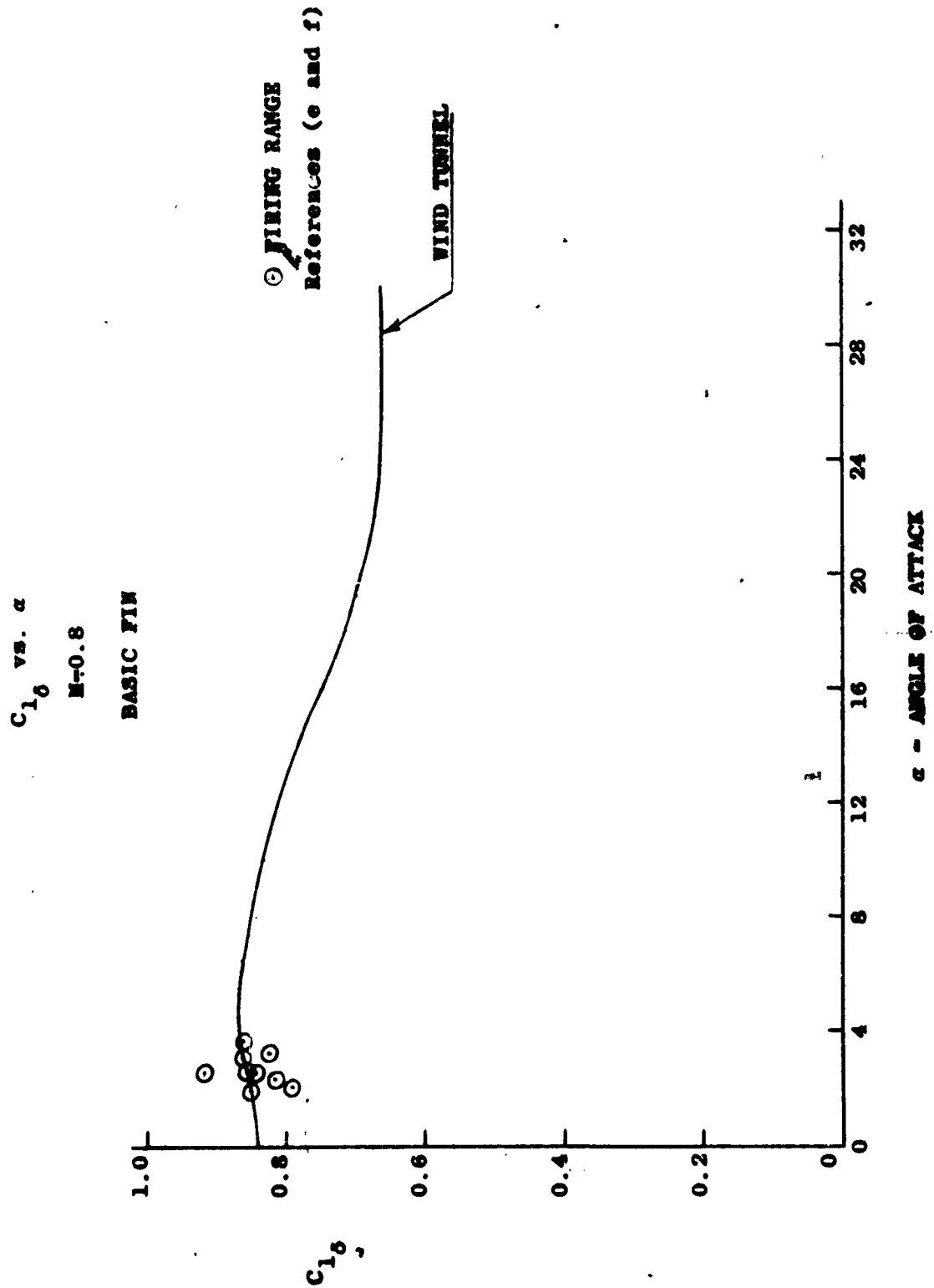
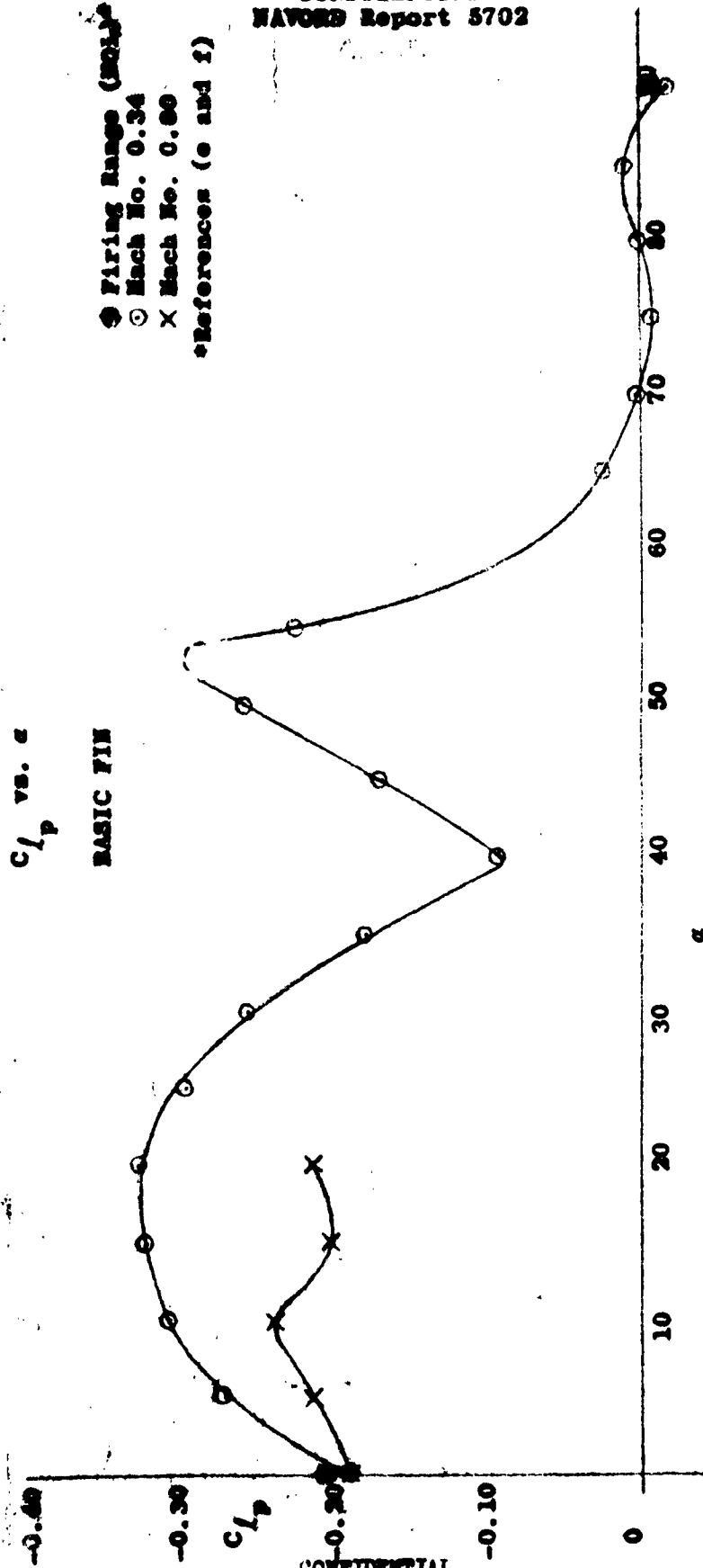


Figure 26

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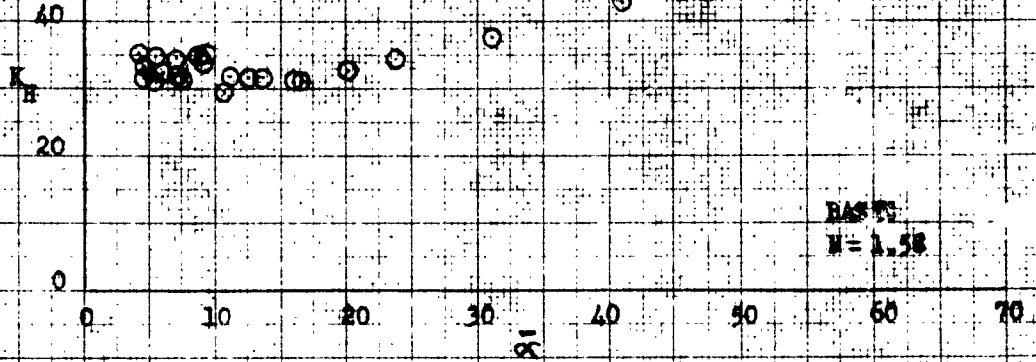


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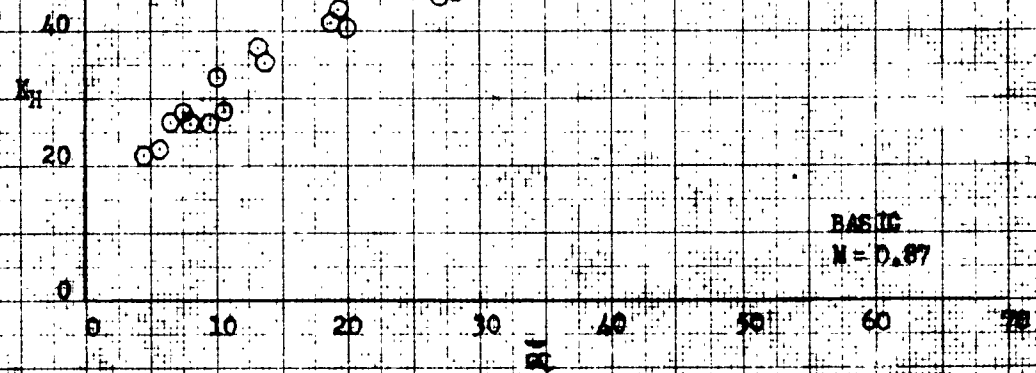
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LOW DRAG BOMB

$K_H$  vs  $R$



BASIC  
 $N = 1.58$



BASIC  
 $N = 0.87$

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Figure 26

10 X 10 TO THE CM. 359-14  
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LOW DECK BOMB

Figure 32

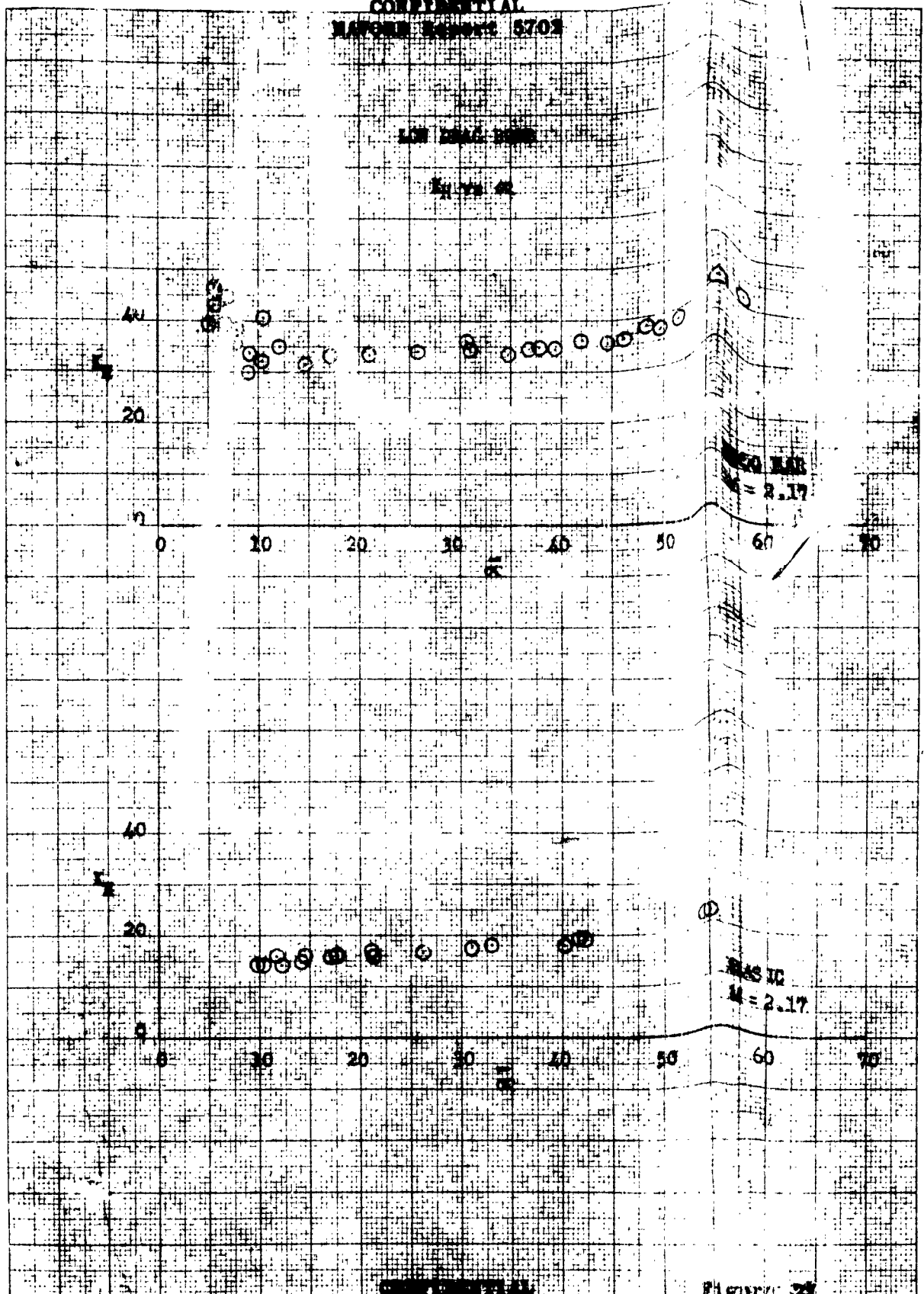
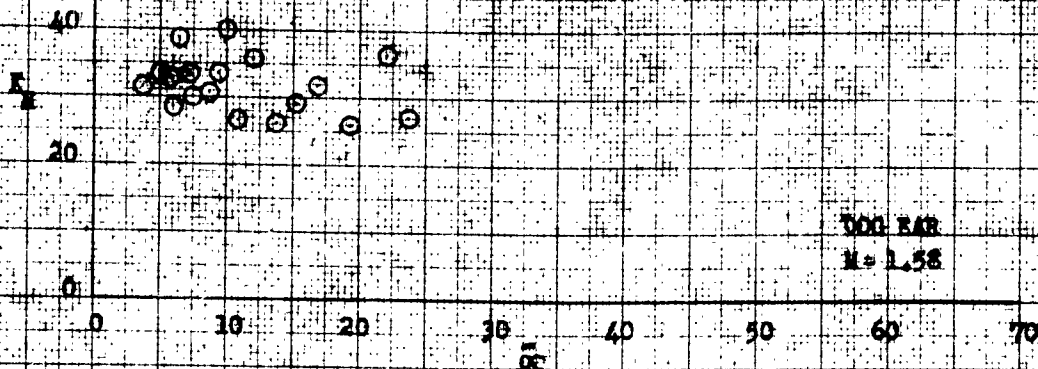


Figure 32

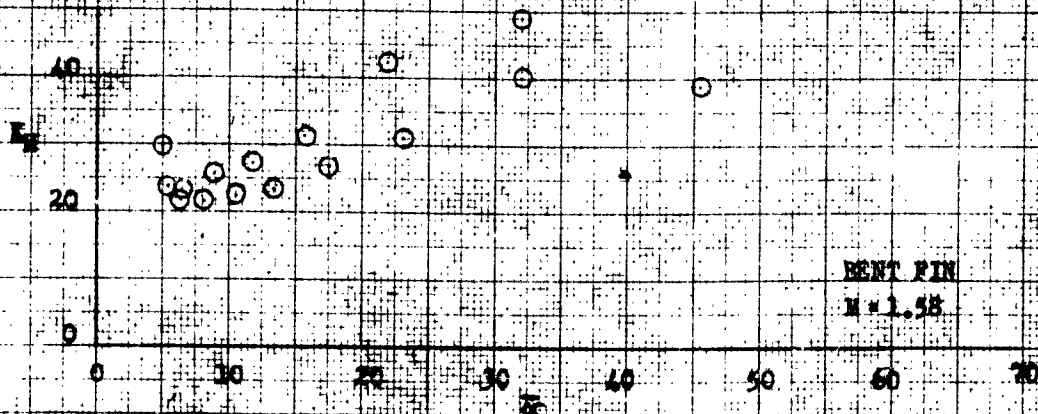
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LOW DRAG BOMB

$K_d \approx 0.0$



TOO EAR  
 $M = 1.58$

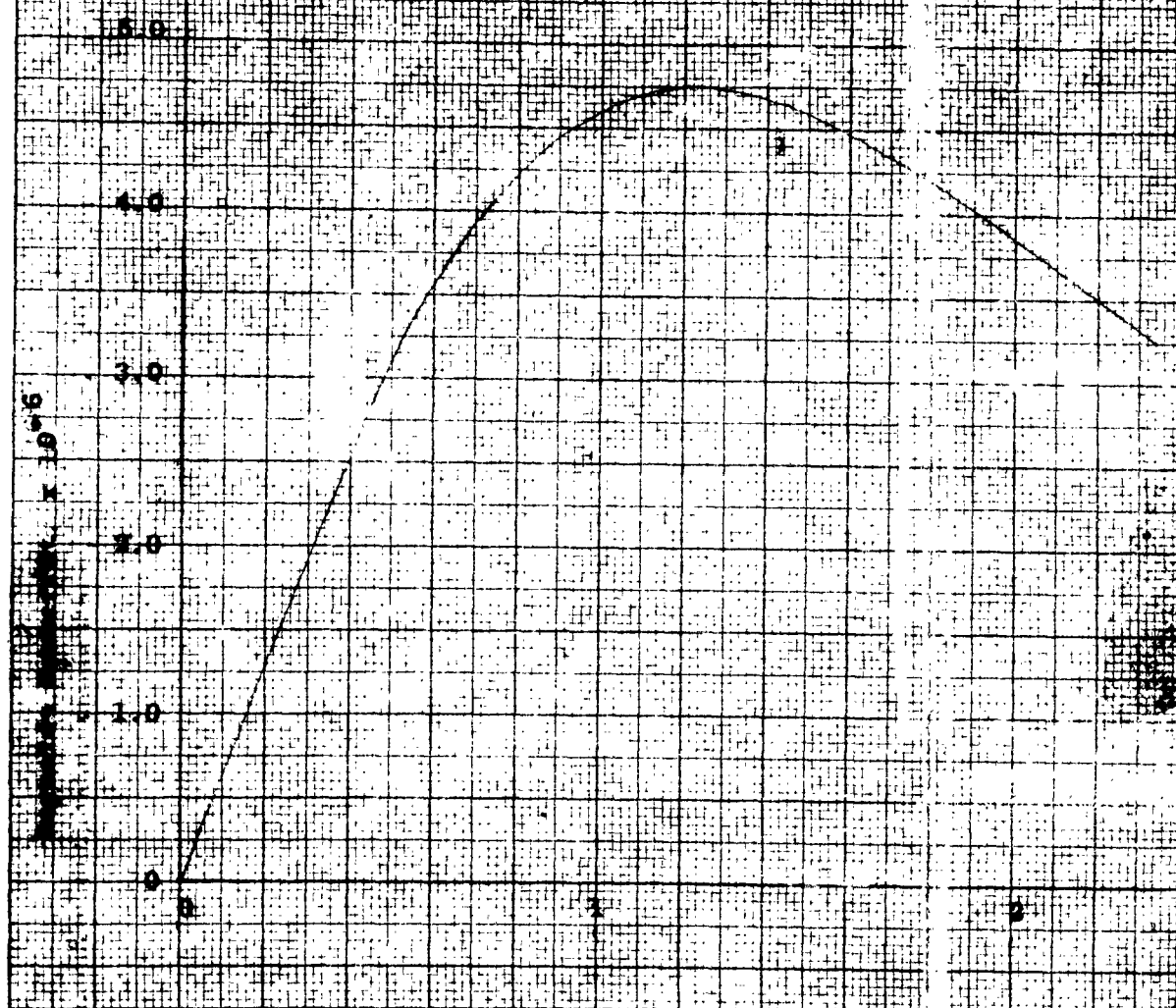


BENT FIN  
 $M = 1.58$

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Figure 20

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 NO. 10. BACH No.



MACH NUMBER

$L$  (rms) = 1.428 ft  
 $L$  (pitch sampling) = 0.113 ft  
 $L$  (roll sampling) = 0.113 ft  
 $L$  (static) = 1.000 ft  
 $L$  (roll free spin) = 1.000 ft

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